All-metal Dual Frequency RHCP High Gain Antenna for the Extreme Environments of a Potential Europa Lander

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***Abstract*— A new all-metal dual-frequency RHCP high gain antenna is under development at NASA's Jet Propulsion Laboratory for a potential Europa Lander. The antenna is mainly made of metal so it could survive the harsh environment conditions of Europa (i.e. very low temperature and high radiation and ESD levels). The antenna is flat to meet drastic volume constraints and has efficiencies higher than 80% at both the uplink and downlink X-band Deep Space frequency bands. This antenna is a key component for the potential mission enabling Direct Link to Earth (DTE) without any relying on an Orbiter to relay the data.**

***Index Terms*—antenna, array, stripline, waveguide, dual frequency, DTE, DFE, telecommunication, patch.**

I. INTRODUCTION

Europa Lander is a proposed NASA astrobiology mission concept that would place a lander on Europa, a moon of Jupiter which is thought to have a liquid ocean under its icy surface as well as water plumes. If selected and developed, the Europa Lander could be launched as early as 2025 to complement the science undertaken by NASA's Europa Clipper mission. The objectives of the Europa Lander would be to search for biosignatures at the subsurface, to characterize the composition of non-ice near-subsurface material, and determine the proximity of liquid water and recently erupted material near the lander's location [1].

For telecommunication, the Europa Lander Project is exploring the possibility of relying solely on communication with Earth, Direct-to-Earth (DTE), rather than relaying signals via a nearby spacecraft. This would require a large antenna aperture and a high transmitter power of at least 100W. The antenna must operate well at both the uplink (7.145-7.190 GHz) and downlink (8.40-8.45GHz) Deep Space frequency bands and must handle up to 100 W of input power in a vacuum.

The Europan environment presents extreme challenges due to its high radiation and ESD levels and ultra-low temperatures. In addition to these severe environment conditions, the baseline mission concept has tight volume constraints forcing the antenna to be completely flat and limiting its size. To withstand the harsh temperature conditions and radiation levels, the antenna should be made mainly of metal.

The maximum aperture area that would be available is 82.5cm × 82.5cm and therefore, very high efficiency (>80%) is required to close the link from Europa. Several antenna technologies,

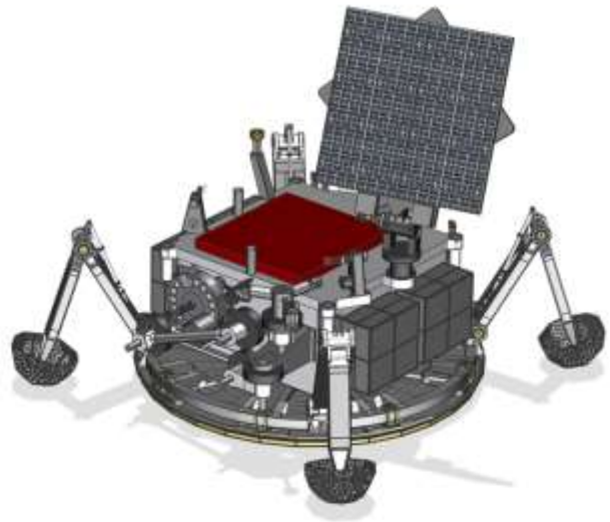


Fig. 1. An artist's concept of a potential Europa Lander with the all-metal dual-frequency RHCP HGA for DTE communication.

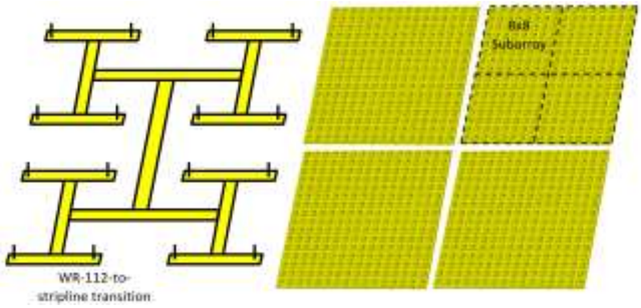
such as RLSA [2] or metasurface antennas [3],[4], were initially considered but found not to meet the high efficiency requirements at both frequencies.

Researchers have investigated different approaches to obtain dual-band or wideband performance in CP patch antennas, including stacked patch antennas [5], slotted patch shapes, slotted ground planes [6], E-shaped [7], U-slot [8], L-shaped [9], and so on. None of the aforementioned solutions are compatible with all-metal solutions that could potentially scaled to a very large array.

NASA's Jet Propulsion Laboratory (JPL) is developing a new type of all-metal RHCP patch array with the potential of demonstrating more than 80% efficiency at both uplink and downlink frequencies. A prototype was fabricated and tested.

We strongly believe that the proposed all metal dual-band RHCP high-gain antenna will pave the way for the next generation of Deep Space DTE/DFE antennas, enabling revolutionary new concepts for space exploration in harsh environments.

Fig. 2. Single element providing RHCP at Tx and Rx frequency bands with a single feed point.



(a) (b)

Fig. 3. (a) 1-to-16 waveguide power divider to excite each subarrays (a subarray is a 8×8 patch array fed by a stripline feed network). (b) The all-metal dual-frequency RHCP HGA for DTE/DFE. 32×32 patch array.

II. Antenna Description

A. *Antenna requirements*

To satisfy the dual-band communication link with NASA's Deep Space Network at the X-band, the antenna would need to meet stringent requirements across both uplink and downlink frequency bands with a sufficient thermal guard band. The antenna should be circularly polarized. Its efficiency should be higher than 80% at both frequency bands to provide at least a gain of 36.0dBi and 37.1dBi at 7.19GHz and 8.425GHz, respectively. The antenna axial ratio should be better than 3dB. The antenna return loss should remain above 14dB. It should survive and perform at 50K (~ -223°C) and high radiation levels. It should also be immune from electrostatic discharge (ESD). The antenna should also handle an input power of 100W continuous wave in vacuum. Finally, the antenna needs be flat and should fit in a confined volume of 82.5×82.5×3 cm^3. It is important to note that the antenna pointing to Earth in azimuth and elevation is enabled by a mechanical gimbal.

B. *Antenna design*

Single element

The key innovation to support the needed requirements is the single element providing RHCP at both uplink and downlink frequency bands (Fig. 2). This element is single-fed, as shown in Fig. 2, which simplifies the feeding network and the antenna fabrication and assembly. This patch element is entirely made of aluminum and is grounded to the antenna ground through a structural post. This structural post does not affect the antenna performance, as it is located where the current is null. The single element is optimized in

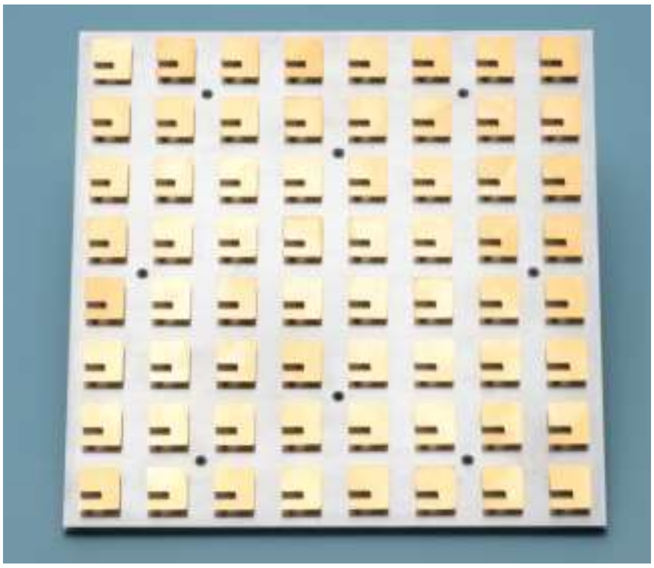


Fig. 4. Photography of the 8×8 subarray.

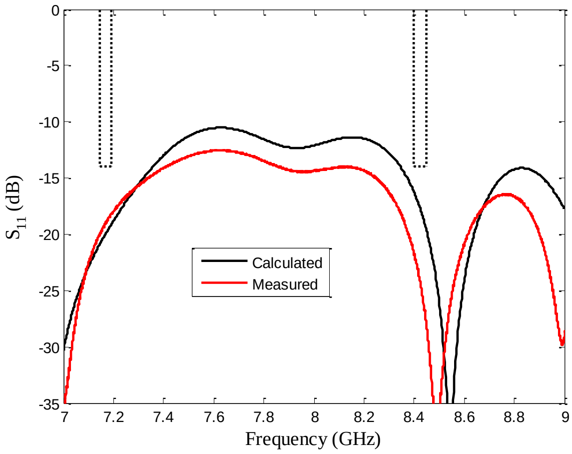


Fig. 5. Calculated and measured reflection coefficient of a potential Europa Lander subarray (8x8 patch subarray).

an infinite array to obtain the required axial ratio and impedance. Once the performance of the single element is met, its performance in an array is verified.

DTE antenna: 32×32 patch array

The proposed DTE antenna consists of 32×32 patch array (Fig. 3). The 32×32 patch array would be composed of four panels. Each panel is made up of four subarrays (Fig. 3b). Each of the 8×8 patch subarray elements are fed using air stripline which is housed under the top ground plane. Each subarray is fed using WR-112 waveguides beneath the antenna as shown in Fig. 3a. Using waveguides to feed all 16 subarrays allows the antenna to support high input or transmitter power levels. For an input power of 100W, the power seen at the stripline input would be 6.25W. It also simplifies the matching network. A WR-112 waveguide to air-stripline transition was designed specifically for this antenna. The spacing between each patch element is $0.62 \cdot \lambda_0$ and was chosen to fit the antenna in the allocated volume. This simple, building block, antenna

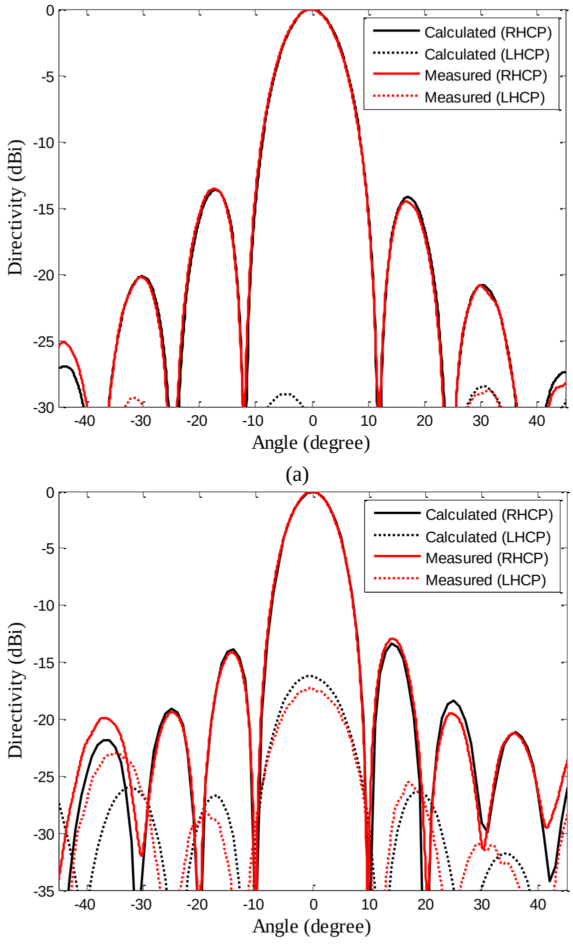


Fig. 6. Calculated and measured radiation pattern of the subarray (8×8 patch array) (a) at 7.1675GHz and (b) 8.425GHz.

architecture compartmentalizes the design challenges that must be addressed and allows the designers to reuse solutions as needed. A gain of more than 36.0dBi and 37.1dBi is reached at uplink and downlink frequency bands, respectively.

8×8 subarray

The subarray is an 8×8 patch array fed using an air stripline feed network (Fig. 4). The air stripline is very low loss (i.e. less than 0.2dB). The thickness was chosen to have sufficient margin against multipaction (i.e. more than 20dB). A subarray was fabricated and tested. The calculated and measured reflection coefficient of the subarray is shown in Fig. 5. They are in excellent agreement. From 7GHz to 9GHz, the reflection coefficient is below -10dB.

The calculated and measured radiation patterns of the subarray are shown in Fig. 6. The radiation pattern are also in excellent agreement. The antenna directivity, gain, and axial ratio are shown in Table I.

C. Comparison with state-of-the-art

The performance of the proposed antenna is compared to the HGA antennas operating on Mars on the Curiosity rover

TABLE I. Calculated and measured directivity, gain, and axial ratio of the 8×8 subarray.

	Directivity (dBi)		Gain (dBic)		Axial Ratio (dB)	
Frequency (GHz)	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
7.1675	24.9	24.9	24.5	24.1±0.4	0.3	0.3
8.425	26.0	26.0	25.6	25.3±0.4	2.7	2.2

[11], Opportunity rover [12], and to a spiral radial line slot array antenna [2] in Table II.

The metal patch array presented here has significantly more aperture efficiency than either of the listed antennas. The radial slot array antenna [2] exhibits low efficiency (i.e. 37% and 18%) and as a result, the antenna needs to be significantly larger to achieve the same gain. Hence, the directivity is greater and the gimbal pointing accuracy is more drastic.

The Mars Science Laboratory high-gain antenna [11], currently operating on Mars on the Curiosity Rover, exhibits higher efficiency compared to the radial slot array but would not survive the harsh environment of Europa. It would also not meet the gain requirement within the allocated space.

The Mars Exploration Rover high-gain antenna’s [12] performance are comparable to that of the antenna on MSL. Due to the resonant nature of the dipole elements, this antenna functioned best over at the downlink frequency band but provided acceptable performance at the uplink frequency band. The antenna aperture efficiency is on the order of 25% and 49% at uplink and downlink frequency bands, respectively.

Due to the 8×8 subarray gain, size, mass, and power handling capabilities, this subarray is a strong candidate for future Mars Rover missions enabling higher data rate when combined with a high-power amplifier (i.e. 100W traveling wave tube as opposed to the currently used 15W solid state power amplifier). This is a game changing technology not only for the potential Europa lander but for any future rover mission requiring DTE.

TABLE II. Performance comparison with other dual-frequency high gain antenna for space applications.

	Aperture Efficiency (%)	**Gain (dBic)**	**Area (cm^2)**	**HPBW (degree)**	**Mass (kg)**
Bray [2]	37 / 18	25.3 / 23.5	1256.6	6.0 / 5.1	1.24
MSL [11]*	49 / 44	22.9 / 23.8	551.2	10.0 / 8.4	1.4
MER [12]*	25 / 49	20.5 / 24.8	615.8	10.0 / 8.4	1.1
This work	**84/ 80**	**24.1 / 25.3**	**428.5**	**10.4 / 8.7**	**0.5**

* Fully qualified antennas.

D. Space Qualification

We are currently building the 32×32 patch array prototype. This antenna will allow us to perform vibration, pyroshock, and acoustic tests. The antenna was submitted to 4 thermal vacuum cycles between +150ºC to -170ºC. The antenna reflection coefficient remains unchanged.

The 8×8 patch array was also exposed to an accelerated radiation test to assess the impact of radiation on the antenna performance. The radiation test was performed in the Dynamitron at NASA JPL at -172C on the 8×8 patch array to assess he effect of Total Ionidizing Dose (TID ~ 3Mrads) and iESD. As the antenna is being bombarded by electrons, any discharges are being measured. The S_{11} was not affected and not damage to the substrate was observed. This demonstrates that the antenna is designed correctly to survive and operate in the Europan environment. The reflection coefficient of the subarray is shown before and after the radiation test in Fig. 7 with no significant change.

A multipaction test is on-going at JPL and the results will be presented during the conference. However, more than 20dB margin is demonstrated in simulation.

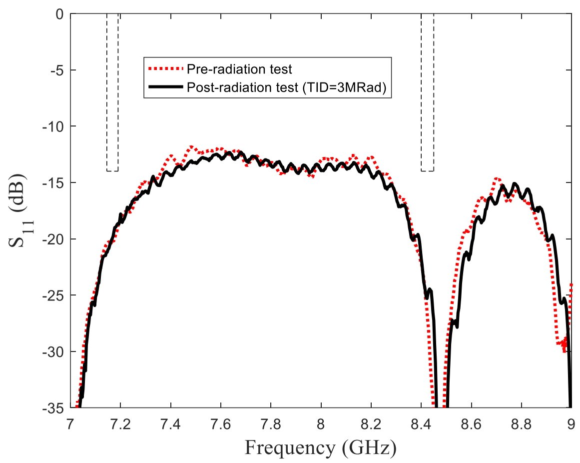


Fig. 7. Calculated and measured reflection of the 8×8 patch array before and after an accelerated radiation exposure (TID of 3Mrads).

III. Conclusion

The high-gain antenna for a potential Europa Lander was introduced conceptually. The proposed antenna consists of 16 sets of 8x8 element patch subarrays. Low-loss air striplines are employed to feed the 8x8 patch elements within each subarrays. Each subarrays are fed using a 1-to-16 waveguide power divider.

The antenna can easily sustain the input power of 100W in vacuum and it was designed to survive the harsh environment of Europa (i.e. high radiation and ESD levels and low temperatures).

A prototype of the 8×8 subarray is currently under fabrication. Measurement results will be presented during the conference.

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